

## MONITORING WORK PARAMETERS FOR ROAD TRANSPORT MEANS

Radu Ciuperca, Ancuta Nedelcu, Ana Zaica, Alexandra Anghel

National Institute of Research-Development for Machines and Installations Designed to Agriculture and Food Industry, Romania

ciupercaradu@yahoo.com, nedelcuus@yahoo.com, zaica\_ana@yahoo.com, anghel.alexandra@yahoo.com

**Abstract.** The performance of the transport means is also determined by the rolling systems, which have major economic and environmental implications caused by the loads to be carried, the travel speeds, the constructive and functional characteristics, the air pressure in the tires with direct implications on the compaction and wear of the rolling track, tire tread wear, rolling resistance and implicitly of the cost of the transport operation itself. The subject of the present paper is the research carried out on a moving articulated vehicle made up of an agricultural tractor and semi-trailer, aiming to continuously monitor the dynamic parameters of the vehicle. We present the mathematical relations expressing the action of the semi-trailer on the tractor, represented by connecting forces, moments and loads, identifying in particular the reaction of the ground on the semi-trailer rolling system and load transfer from the semi-trailer to the tractor, which contributes to its additional loading, these two parameters being followed. For the continuous measurement and monitoring of the two parameters, in real time, a load monitoring installation was built and assembled on the articulated vehicle, consisting mainly of force transducers, force amplifiers, micro PLC operating terminal and other connection elements. Registrations made during the experiments are managed by software specially created for these researches. Experiments were carried out both for stationary and for all travel regimes of the articulated vehicle, namely acceleration, deceleration and sudden braking, the results obtained from the tests allowing us to establish the veracity of the mathematical relations, on the one hand, and the evolution of the measured parameter value in the three travel regimes, on the other hand.

**Keywords:** transport, monitoring, control, safety.

### Introduction

The main working parameters of the means of road transport are the maximum weight transported (mass of the product transported + mass of the means of transport), the travel speed and the braking parameters.

Depending on these parameters, the proper rolling system, the constructive and functional characteristics are established, with direct implications for the rolling track compression and wear, tyre tread wear, rolling resistance and implicitly of the cost of the transport operation itself [1-3].

During running of the system made up of a tractor vehicle (hereinafter referred to as auto-tractor) and a trailer, additional load (weight) transfers from the trailer to the tractor appear. These transfers occur both during normal running, on a horizontal road, when at the constant weight transferred as a result of the construction of the means of transport (for example, a semi-trailer) an additional weight is added caused by the inertia force of the means of transport appearing at deceleration in case of normal rolling, downward rolling or during system braking [4-6].

On the contrary, in the acceleration or upward rolling phases there is a load discharge of the tractor.

At present, for the existing transport systems these additional weight transfers to the auto-tractor [1; 2; 4; 5; 7; 8] cannot be quantified, except theoretically, as too much, uncontrolled load intake can affect the quality of the transport [9] or in extreme cases can lead to occurrence of malfunctions that can cause accidents.

Existing rolling systems perform as the main functions of load supporting, rolling, braking and partial shock absorption.

The rolling system studied in this paper is equipped with a load monitoring installation that allows, besides the functions that any existing system performs, to continuously measure the weight of the means of transport by providing real-time information on the weight variation transferred to the tractor in the aforementioned transport situations, as well as on the air pressure in the tires according to the transported load.



The normal reaction of the ground on the semi-trailer wheels is determined from the moment equation written in the coupling point C, according to the relation (5):

$$Z_s \cdot L_1 + F_{fs} \cdot h_c - M_{rs} - F_{is} (h_s - h_c) - G_s \cdot a_s \cdot \cos \alpha - G_s \sin \alpha (h_s - h_c) = 0. \quad (5)$$

Replacing  $F_{fs}$  and  $M_{rs}$  in relation (5) with their expressions given by relations (2) and (3) and making the grouping of common factors, the expression of the  $Z_s$  reaction according to the relation (6) is determined:

$$Z_s = \frac{(F_{is} + G_s \cdot \sin \alpha) \cdot (h_s - h_c) + G_s \cdot a_s \cdot \cos \alpha}{L_1 + f(h_c - r_s)}. \quad (6)$$

Component R is determined by the relation (7):

$$R = G_s \cdot \cos \alpha - Z_s$$

Or replacing component R with the expression in relation (6) results in the following:

$$R = \frac{G_s \cdot \cos \alpha [b_s + f(h_c - r_s)] - (F_{is} + G_s \cdot \sin \alpha) \cdot (h_s - h_c)}{L_1 + f(h_c - r_s)}. \quad (7)$$

Replacing  $Z_s$  reaction in relation (4) with its expression in relation (6), grouping the terms, results in the expression for  $F_t$ , according to relation (8):

$$F_t = \frac{f \cdot G_s \cdot a_s \cdot \cos \alpha + (F_{is} + G_s \cdot \sin \alpha) [L_1 + f(h_s - r_s)]}{L_1 + f(h_c - r_s)}. \quad (8)$$

The ground normal reactions on the wheels of the tractor with the semi-trailer are determined from the moment equations written in the support points A and B, the final expressions being according to the relations (9, 10):

$$Z_{t1} = \frac{G_t \cdot b_t \cdot \cos \alpha - (G_t \cdot \sin \alpha + F_{it} + F_a) h_t - R \cdot c - F_t \cdot h_c - M_{rt}}{L}, \quad (9)$$

$$Z_{t2} = \frac{G_t \cdot a_t \cdot \cos \alpha + (G_t \cdot \sin \alpha + F_{it} + F_a) \cdot h_t + R(L + c) + F_t \cdot h_c + M_{rt}}{L}, \quad (10)$$

where  $M_{rt} = M_{rt1} + M_{rt2} = f \cdot r_t (G_t \cdot \cos \alpha + R)$  – rolling resistance moment of the tractor (including the part of the semi-trailer weight R to be distributed to the tractor).  
 $r_t$  – dynamic radius of the tractor wheel, m.

## Results and discussion

The tests were carried out with articulated vehicle made up of an autotractor and a means of transport, in this case a New Holland TD80D agricultural tractor and a one-axle agricultural semi-trailer, Fig. 2, which moves on a horizontal ground, the semi-trailer being equipped with a load monitoring installation.

In this paper we are interested in the sizes that act on the semi-trailer, namely:  $Z_s$ ,  $R$ .

To verify correct functionality of the load monitoring installation, we determined it by weighing, when stationary, using the classic weighing system:  $G_s = 7250$  kg;  $Z_s = 6268$  kg;  $R = 982$  kg.

In a first stage of the tests using the load monitoring installation we determined, when stationary, the mass of the loaded semi-trailer,  $G_s = 7125$  kg and its distribution on the axis. The values measured during the experiments are:  $Z_s = 6168$  kg and the component to be transferred to the tractor,  $R = 957$  kg.

It is to be noted that the differences are insignificant, so the installation is functioning correctly, the deviations being of 1.60-2.6 %, a value falling within the equipment construction error margin.

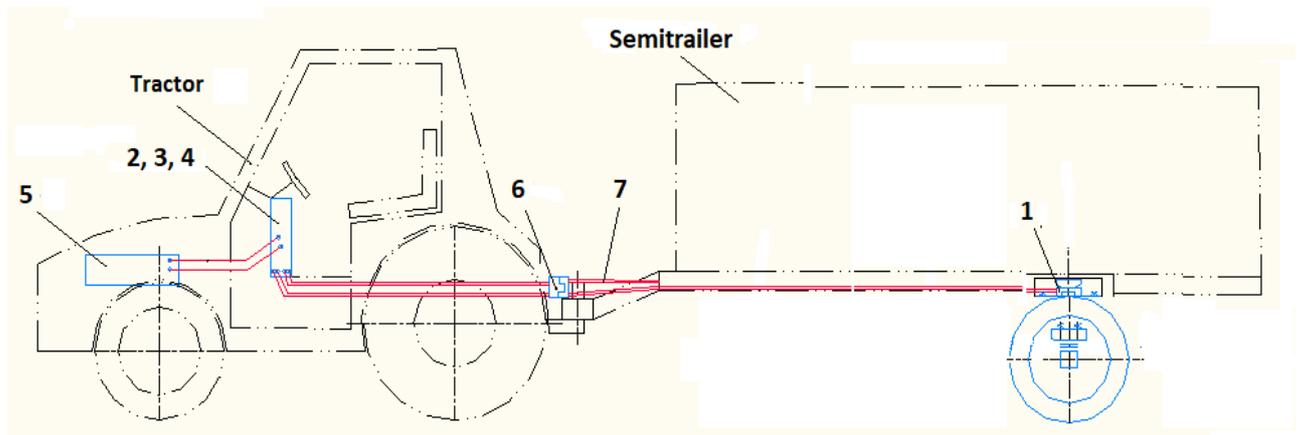


Fig. 2. **Load monitoring installation:** 1 – force transducer; 2 – force amplifier; 3 – micro PLC; 4 – operating terminal; 5 – accumulator battery; 6 – bipolar fuse; 7 – connecting cables

We also measured and calculated the constructive dimensions of the semi-trailer, the positions of its centre of gravity and the coefficient of the masses in rotation motion (for semi-trailer wheels), as follows:

$$L_1 = 4.8 \text{ m}; a_s = 4.15 \text{ m}; b_s = 0.65 \text{ m}; h_s = 1.6 \text{ m}; h_c = 0.45 \text{ m}; r_s = 0.55 \text{ m}; \delta_s = 1.055$$

For  $\frac{dv}{dt}$  was taken as the average value of  $0.3 \text{ m} \cdot \text{s}^{-2}$ , from [1].

The values for  $Z_{sa}$  and  $R_a$  in the case of articulated vehicle acceleration (marked with “a”), on horizontal terrain, are calculated with the relations (6; 7) using the determined and measured values as follows:

$$Z_{sa} = \frac{\frac{7250}{9.81} \cdot 1.055 \cdot 0.3(1.6 - 0.45) + 7250 \cdot 5.15}{4.8 + 0.01(0.45 - 0.55)} = 6326 \text{ daN}$$

$$R_a = \frac{7250 \cdot [0.65 + 0.01(0.45 - 0.55)] - \frac{7250}{9.81} \cdot 0.3 \cdot 1.055(1.6 - 0.45)}{4.8 + 0.01(0.45 - 0.55)} = 924 \text{ daN}$$

Similarly, the values for  $Z_{sd}$  and  $R_d$  are calculated according to the relations (6; 7) in the case of articulated vehicle deceleration (marked with “d”); only that in this case the inertia force of the semi-trailer has the opposite direction of action. Using the measured and calculated values presented above we have:

$$Z_{sd} = 6213 \text{ daN}; R_d = 1037 \text{ daN}$$

The values for  $Z_{sf}$  and  $R_f$  in the case of the articulated vehicle sudden braking (marked with “f”) are calculated with the relations (6; 7), where the inertia force of the semi-trailer has the opposite direction of action and the deceleration value is  $1.45 \text{ m} \cdot \text{s}^{-2}$ , which means the subtraction between deceleration of the tractor itself,  $6.05 \text{ m} \cdot \text{s}^{-2}$  and articulated vehicle  $4.45 \text{ m} \cdot \text{s}^{-2}$ , as follows:

$$Z_{sf} = 5999 \text{ daN}; R_f = 1251 \text{ daN}$$

For moving on slope the calculations are similar only that the slope angle of inclination is introduced in the relations.

Driving tests were performed for two situations commonly encountered during transport, for each situation there were 5 determinations made, namely:

Driving at a constant speed of 30 km·h<sup>-1</sup>, deceleration for a period of 5 seconds, when the operator raises the foot from the tractor accelerator pedal followed by acceleration to 30 km·h<sup>-1</sup>, the results determined for Z<sub>s</sub> and R during deceleration/acceleration periods being shown in Table 1;

Table 1

**Determination of Z<sub>s</sub> and R values in the case of articulated vehicle deceleration/acceleration**

Determined parameter	$\frac{dv}{dt} = 0.3 \text{ m}\cdot\text{s}^{-2}$ Deceleration during driving / Test no.						$\frac{dv}{dt}, \text{ m}\cdot\text{s}^{-2}$			
	1	2	3	4	5	Average	0.1	0.3	0.5	0.7
Z <sub>sd</sub> , daN	6235	6220	6210	6226	6210	<b>6220</b>	6250	6220	6176	6139
R <sub>d</sub> , daN	1015	1030	1040	1025	1040	<b>1030</b>	1000	1030	1074	1111
	Acceleration during driving / Test no.									
Z <sub>sa</sub> , daN	6315	6318	6332	6320	6325	<b>6322</b>	6288	6322	6363	6400
R <sub>a</sub> , daN	935	932	918	930	925	<b>928</b>	962	928	887	850

Driving at a constant speed of 30 km·h<sup>-1</sup> followed by sudden braking to stopping the articulated vehicle, the results determined for Z<sub>s</sub> and R during the braking period being shown in Table 2.

In all the above-mentioned situations, the determined sizes are the soil reaction on the semi-trailer wheels, Z<sub>s</sub>, and the additional load of the rear axle of the tractor R, these sizes being in fact those, the value of which varies significantly during transport.

Since during the testing period the registered values were very numerous, the highest values of each test were mentioned in Tables 1 and 2. Their variation is graphically shown in Fig. 34.

Table 2

**Determination of Z<sub>s</sub> and R values in the case of articulated vehicle braking**

Determined parameter	$\frac{dv}{dt} = 1.45 \text{ m}\cdot\text{s}^{-2}$ Braking / Test no.						$\frac{dv}{dt}, \text{ m}\cdot\text{s}^{-2}$			
	1	2	3	4	5	Average	1.25	1.45	1.65	2.00
Z <sub>sf</sub> , daN	5985	6005	6020	6010	6020	<b>6008</b>	6035	6008	5961	5896
R <sub>f</sub> , daN	1265	1245	1230	1240	1230	<b>1242</b>	1215	1242	1289	1354

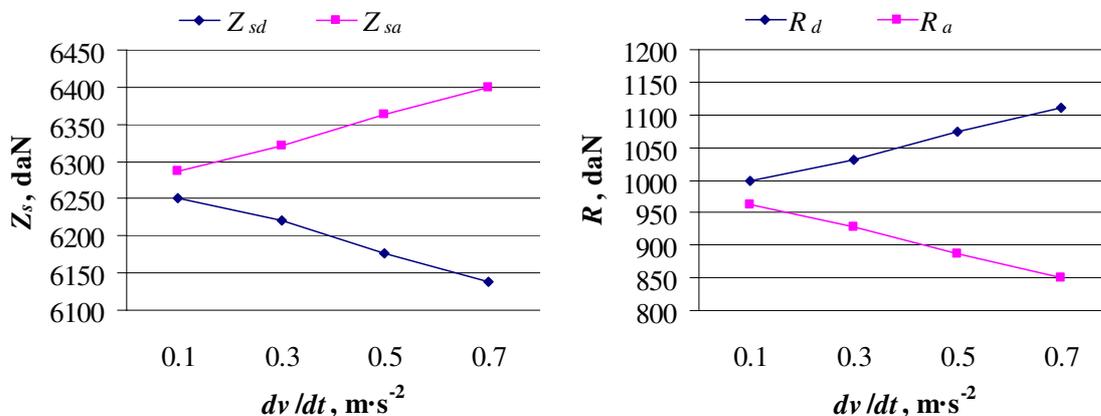


Fig. 3. Variation of Z<sub>s</sub> and R on deceleration/ acceleration

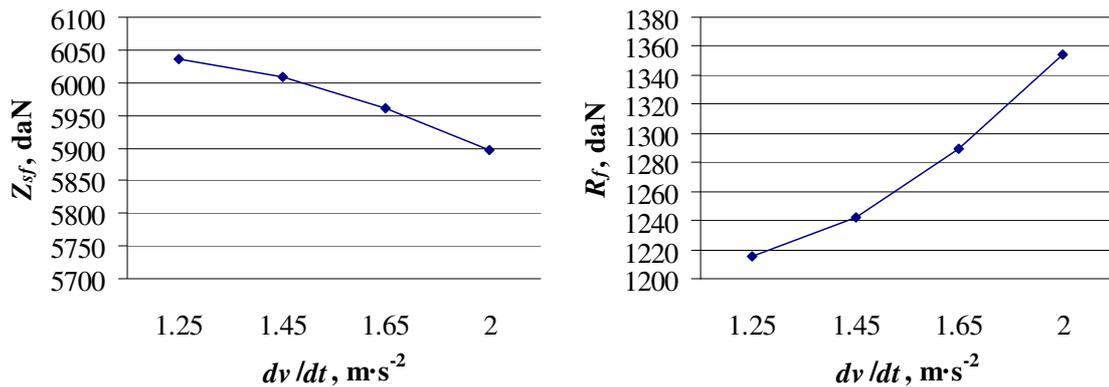


Fig. 4. Variation of  $Z_s$  and  $R$  on braking

### Conclusions

1. During running of a system consisting of a tractor vehicle and a trailer, there are additional load transfers (weight) from the trailer to the tractor, which, at present, can be quantified only theoretically for the existing transport systems;
2. The rolling system covered by this paper is equipped with a load monitoring installation that carries out continuous real-time measurement of the load sustained by the trailer rolling system and its variation as a result of the load transfer to the tractor while driving;
3. The values measured during experimentation for the load sustained by the trailer rolling system, when stationary close to those determined by the classic weighing system, the deviations being 1.75 %, a value falling within the equipment construction error margin;
4. The values measured during experimentation, while the articulated vehicle was running, for the reaction of the ground on the trailer rolling system,  $Z_s$  and for load transfer from the semi-trailer to the tractor,  $R$  are very close to those determined theoretically with mathematical relations, the deviations calculated as the ratio of the theoretically calculated value and mean value measured in the experiments being: for  $Z_{sa}$ , 0.1 % when accelerated; for  $Z_{sd}$ , -0.099 % when decelerated; for  $Z_{sf}$ , -0.0998 % when braked; for  $R_a$ , -0.0995 % when accelerated; for  $R_d$ , 0.0679 % when decelerated; for  $R_f$ , 0.0724 % when braked.
5. The permanent knowledge of the weight distributed to the trailer axle helps us, among others, set up the air pressure in the tires according to their type, the size of the load transported, the condition and the nature of the rolling track in order to achieve an optimal transport operation.

### Acknowledgements

The work was performed under the project “Increasing the competitiveness of SC ELECTROPUTERE VFU PASCANI SA through assimilation into production of an Intelligent rolling system, designed to general and technological land transport equipment”, Contract 5/PTE/2016 funded by the Executive Agency for Higher Education, Research, Development and Innovation Funding - UEFISCDI within the PN-III-CERC-CO-PTE-2016 Program.

### References

- [1] Tecusan N., Ionescu A., Tractoaresi Automobile (Tractors and Automobiles), Editura Didactică și Pedagogică București (Technical Publishing House Bucharest), 1982, pp. 65-88.
- [2] Untaru M, Stoicescu A, Dinamica autovehiculelor pe roti (Dynamics of Wheels Automotive), Editura Didactică și Pedagogică București (Technical Publishing House Bucharest), 1981, pp. 126-146.
- [3] Kumar A. A., Tewari V.K., Gupta C., Kumar N., Visual Basic Program and Instrumentation System for Power and Energy Mapping of Tractor Implement, Engineering in Agriculture, Environment and Food, vol.10, Issue 2, 2017, pp. 121-132.
- [4] Badescu M., Iordache S., Ivancu B., Persu C., Bunduchi G., Epure M., Vladut V., Theoretical Study of the System of Forces and Moments Acting on Tractor-Semitrailer Aggregate, into Rectilinear

- Motion, ANNALS of Faculty Engineering Hunedoara – International journal of Engineering, Tome XII, August 2014.
- [5] Bădescu M., Iordache S., Manea D., Sorică C., Brăcăcescu C., Boruz S., Epure M., Vlăduț V., Analysis of Forces and Reaction Moments Acting on Tractor Semitrailer Agregate on Sloped Roads, ANNALS of Faculty Engineering Hunedoara – International journal of Engineering, Tome XII, November 2014, pp. 29-36.
- [6] Ciupercă R., Popa L., Nedelcu A., Borisov B., Atanasov At.-Braking of trailer endowed with inertial braking system, working in aggregate with tractor, INMATEH - Agricultural Engineering, Vol. 32, No. 3 / 2010, pp. 51-58.
- [7] Iordache S., Boruz S., Vlăduț V., Sorică C., Manea D., Brăcăcescu C., Epure M., The Study of Braking Dynamics on Tractors with Wheels and Influence of the Forces Which Appear at Movement on Braking Capability, ANNALS of Faculty Engineering Hunedoara – International journal of Engineering, Tome XII, November 2014, pp. 73-78.
- [8] Iordache S., Bădescu M., Boruz S., Usenko M., Cujbescu D., Vlăduț V., Study of Tractor Shaft Braking Forces Distribution Influence on Wheeled Tractors Braking, ANNALS of Faculty Engineering Hunedoara – International journal of Engineering, Tome XII, August 2014, pp. 325-330.
- [9] Żebrowski J., Traction efficiency of a wheeled tractor in construction operations, Automation in Construction, vol.19, Issue 2, 2010, pp. 100-108.
- [10] Ciuperca R., Popa L., Nedelcu A., Dynamics of tractor-semitrailer braking system, 47<sup>TH</sup> International Conference of Departments of Design of Machine Elements and Mechanisms, 2006, Prague, pp. 43-47.